Energy Performance: A Comparison of Four Different Multi-residential Building Designs and Forms in the Equatorial Region

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***Abstract* - Building sector has been identified as a major energy consumer with nearly half of the world's energy used is associated with providing environmental conditioning in buildings. Approximately, two third of this is for heating, cooling and mechanical ventilation. Therefore, there is a need for optimizing the building design which collaborates with surrounding environment in enhances the energy conservation programme. Energy consumption evaluation and audits for buildings is the most important step that can contribute to energy conservation. As preliminary studies to this research, four low-rise residential college buildings with specific layout were selected in finding the relationship between green/passive building strategies and energy performance. The study initial approach was to critically analyse the design of the selected buildings through scaled drawings and site visits. Comparison of the two were carefully made to obtain current and post renovation conditions and surroundings as most of the drawings were drawn 30 to 40 years back. The elements of bioclimatic design were implemented as matrixes or criteria, particularly on natural ventilation and day lighting. Then, the energy performance was crucially audited to find out Building Energy Performance (BEP) acknowledged as energy use per unit floor area, and Energy Efficiency Index (EEI) to elaborate the kWh/m^2/year of each residential college for five years duration. As initial findings, the implementations of appropriate green building strategies is able to provide positive impacts to the overall energy performance of the residential colleges.**

Keywords - Building Energy Performance (BEP), building design, energy audit, Energy Efficiency Index (EEI), green building

I. INTRODUCTION

The Malaysian National Energy Efficiency Master Plan 2010 outlined productive use of energy consumption to promote energy efficiency in built environment. This has also been highlighted in Tenth Malaysia Plan with a target to achieve cumulative energy saving of 4,000 kilo tones of oil equivalent (ktoe) by 2015 [1]. This includes residential and building sector as being the third largest energy consumer in Malaysia [2]. As reported in 2009, the commercial and residential sector accounts for about 13% of total energy consumption in addition to 48% of electricity consumption in Malaysia [3]. Thus, the building sector is a critical area to be studied for its energy performance [4], whilst improving thermal and visual comfort as well as enhances energy security.

Green building practices, which is also acknowledged to share sustainable building principles, eco design building, bioclimatic design building and low impact design, can significantly reduce or eliminate negative environmental impacts and improve existing non-sustainable design, construction and operation practices [5]. This can be achieved with more efficient use of natural resources, especially energy and water, and using renewable energy in the operational stage of the buildings.

Energy efficiency in buildings can be achieved in many ways, but fundamentally, one should not ignore the basics of the passive building designs. Passive building design is one of the main factors determining the building's energy performance, besides building services design and appliances and occupant behaviours [3], the latter factors are difficult to control and maintain. In the tropics, as much as 60-70 % of the total energy in non-industrial buildings is consumed by air-conditioning, lighting and mechanical ventilation [6]. Thus, natural ventilation and daylighting are two well known strategies used to reduce a building's energy consumption specifically for cooling and lighting. The peak-cooling load (which determines the maximum demand of energy) and the annual electricity consumption can be reduced substantially by 10 % and 13 %, respectively, through the application of day lighting [7, 8]. Approximately 43 % of energy reduction can be achieved by using combinations of well-established technologies such as glazing, shading, insulation, and natural ventilation if the building itself is designed taking into account the climate of the site [6]. Natural ventilation combined with solar protection is the most efficient building design strategy to achieve thermal comfort without resorting to mechanical cooling [9]. This strengthens the fact that, sufficient provision for air movements and daylighting are key considerations in building design in the tropical regions. Nevertheless, thermal comfort in the building should not be compromised whilst implementing passive and low energy systems to meet sustainability requirements.

The effectiveness of green building practices in a building can be verified through energy audit, which includes the evaluation of consumption patterns and followed by the identification of specific energy saving measures. These two steps are the most major ingredient of the energy management activity [10].

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There are different levels of sophistication, energy audit can be divided into two types which are walkthrough audit; simple study of some major equipment/systems and detailed audit; thorough study of practically all equipment/systems [11]. The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) [12] stated three different level of analysis for energy audit as listed below:

- *Preliminary energy use analysis*
  The building's energy consumption is evaluated by developing Energy Use Intensity (EUI) resulted from existing annual utility billing.
- *Level I - Walkthrough analysis*
  A visual inspection of building's mechanical and electrical systems through interview of building operating personnel and evaluation of non-energy related capital investments.
- *Level II - Energy survey and analysis*
  More detailed building survey and expands on the walk-through analysis by conducting field measurements while energy saving and cost analysis are also completed.
- *Level III - Detailed analysis of capital-intensive modifications*
  Built up the dynamic energy model of existing systems by using software to understand the return on investment of each option which also known as investment grade audit.

The multi-storey residential building typically plays a role as student halls of residence, key worker accommodation, care homes and sheltered house, containing catering facilities, lounges, dining rooms, health and leisure areas, offices, meeting rooms and other support areas such as laundry facilities [13]. Currently, majority of the university students are Millennial Generation, also acknowledge as New Boomers Generation, who born from 1980 onwards, they are brought up using digital technologies, electrical gadgets and automobiles [14]. They can be considered as the largest consumers of energy as compared to earlier generations, Baby Boomers (who born from 1946 to 1964) and Y (who born from 1965 to 1980) [15].

The aim of this study is to analyse the energy performance of four residential colleges which are low-rise multi-residential building, regarding the implementation of green building strategies particularly on day lighting and natural ventilation. Thus, the effects of the recent adoption of green building strategies in influencing the total energy consumption at residential colleges will be revealed by evaluating the electricity consumption patterns. Indirectly, this study will also demonstrate the electricity consumption patterns of the Millennial Generation living in residential colleges in Malaysia. It is hope that this study will be able to fill in the current knowledge gap on passive energy design in residential college buildings as most of the studies reported in the literature had strictly focused on residential houses, such as single storey, double storey, flat houses and apartments [16, 17, 18, 19], rather than residential college buildings, which may have different layouts, services, users and living patterns.

II. Research Design and Approaches

A. Building Description

Four residential colleges with different designs, forms, layouts and capacities were chosen in this study in finding the relationship between different green/passive building strategies implemented and performance of electric use. There were, K1: linear arrangement with fixed opening at the both end of corridor at each level (705 residents), K2: linear arrangement with fixed opening at the end and middle of corridor at each level (1,001 residents), K3: internal courtyard (885 residents), and K4: internal courtyard with balcony at each residential unit (897 residents). All of the case studies are located in the University of Malaya Kuala Lumpur campus situated at 3°7'1"N and 101°39'12"E. The salient climate for Kuala Lumpur is consistently hot and humid all year with annual average temperature between 23 to 32°C and average precipitation reaching up to 190mm. Kuala Lumpur is affected by the weaker south-east monsoon from April to September [20] though afternoon rain accompanied by thunderstorms are common.

In each case study, the residential units are limit to two occupants per room and open to local and international students. K1 is the oldest residential college, established in 1963 while K4 is the newest, established in 1997. Each residential college comprises one administrative block and four to six residential blocks. All administrative blocks are equipped with air-conditioning. The residential units/rooms at the residential blocks are non-conditioned but are provided at least with one ceiling fan, two fluorescent lamps in each unit.

B. Building Design Studies

The blue prints, which included a site plan, architectural drawings and structure drawings, were the main source of data for the building design studies. Site visits to each residential college were also carried out in order to gauge actual conditions, since most of the drawings were drawn 30 to 40 years ago, and since then, numerous renovations and add-ons have been carried out to increase the residences' capacities. The elements of bioclimatic design (passive mode) introduced by Yeang [21] were adapted as matrixes for assessing the building's design in adapting green building concepts, with particular focus on the application of natural ventilation and day lighting.

C. Performance of electric use

The efficiency of electricity use in each residential college was evaluated by adapting a method from Saidur [22] who estimated energy intensity, EI in kWh/m^2 by using following equation:

$$EI = AEC / TFA$$

where, AEC is annual energy consumption (kWh) and TFA is total floor area (m^2). Principally, Kamaruzzaman and Edwards [23] stated that the energy use per unit floor area can be described as 'Normalised Performance Indicators' (NPI), which is also known as the energy use index or Building Energy Performance (BEP) [11].

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Consequently, the term BEP will be used in this study to indicate the performance of electric use at the residential colleges, while Energy Efficiency Index (EEI) will be used to elaborate kWh/m^2/year [24, 25]. Referring to Iwaro and Mwasha [26], energy use in residential buildings is usually 10-20 times lower compared to office buildings. Thus, the electricity usage in residential buildings in Malaysia amounts to approximately 10 to 25 kWh/m^2/year if the electricity use in office buildings in Malaysia is in the range of 200 to 250 kWh/m2/year [27].

The energy consumption data were collected and analysed out of a five year period, beginning from 2005 until 2009, while total floor area was calculated from the building plans. On-site measurements were also carried out for the purpose of obtaining accurate facts, since errors arose from the same sources as mentioned earlier, such as outdated drawings and recent renovations. Further statistical analysis was carried out using SPSS 15.0 (Standard version) computer software package. Descriptive statistical analysis was performed to analyze mean, median, mode, standard deviation, variance and range for comparison purposes.

III. Results and Discussion

The characteristic and green building strategies demonstrated by the four residential colleges K1, K2, K3 and K4, particularly regarding natural ventilation and day lighting, are presented in TABLE I.

Roughly, the buildings' characteristics of K1 and K2 are quite similar when both of these residential colleges were built with a linear arrangement and large open ended corridor. Unfortunately, there are more green building strategies pertaining wind and natural ventilation were implemented at K1 as compared to K2. There are adjustable openings at K1 with louver windows at both ends of the common corridor. Vice versa at K2, features large fixed openings with wide horizontal awning as part of solar control devices and open corridors at each floors in the middle of the building to increase the effects of natural ventilation and daylighting. Due to this passive design, the lamps in the common corridor need not be continuously switched on during most part of the day as compared to K1. Solar control devices, in forms of horizontal overhangs and awnings are also available at both residential units with vertical overhangs at window openings at some of residential building at K1. The building massing of K1 and K2 are not orientated to the sun path, which directly eliminates thermal gain into the buildings. In addition to K1, there were low exhausted opening and wing wall above the entrance door and wall of each residential unit/room which became an advantageous in encourage natural ventilation and daylight inside the residential unit/room compared to K2. Nevertheless, with regards to the design aim of glare protection, small window areas of residential units/rooms were instated at K2, resulting in the smallest window to wall ratio among the four residential colleges. The same approach can also be seen in the staircase area, where small adjustable opening devices were set up, capable of providing adequate day light and air circulation within these two areas. It was quite different with K1 where there are fixed opening devices in larger scale which creates wind pressure effects.

Regarding on landscape, K1 stated the smallest percentage among other residential colleges which was 52.25%, followed by K2 with 52.65%. With the open gable roof design, there is no potential for a rooftop garden at both residential colleges.

K3 is the leading residential college due to the design of its residential unit that allows for the best utilisation of natural ventilation and day lighting. The college's courtyard, the wing walls on the top of entrance door and wall, functions in promoting air circulation and allowing day light inside the residential unit/room. As a result, sufficient daylighting is obtained throughout the corridor which limits the usage of artificial lighting most part of the day. In addition, the building's north-south orientation heavily reduces the thermal gain into the residential units/rooms, only the services areas, such as the toilets, bathrooms, stores, staircases and balconies, are located at a west-east orientation. The high penetration of sunlight into the toilets and bathrooms lowers the humidity levels thus eliminating any risk of mould growth in these areas, which can be a major contributor to unhealthy buildings and poor indoor air quality. Regarding the enclosural and facade design, K3 was designed with special features such as glare protection and adjustable natural ventilation options. The two types of windows, centre pivot and awning, which are tinted, offer the occupant the possibility to channel the outside air/wind, although the position of the windows and the building orientation are not in accordance with the wind flow direction, southwest. Moreover, the amounts of daylight penetration can be controlled even though each residential unit stated the biggest window to wall ratio. The awning windows that are located above the centre pivot directly play a role as high level exhaust opening and articulate light shelves. On the landscape perspective, K3 has the largest green area exceeding 60% while flat roof design offers a big potential for the creation of a rooftop garden in the future, which would directly help to decrease the heat penetration through the roof.

Similar to K3, K4 also has a layout with a courtyard but not placed centre of the residential unit. The residential buildings are orientated towards north-south and west-east resulted from L-shape of the building's floor plate. There are four residential units/rooms, with their entrance doors facing each other, creating a cubicle. It is observed that the corridor lamps are not continuously switched on during day time as each cubicle is connected by an open corridor that faces the internal courtyard. The presence of wall openings creates wind pressure in the cubicle, which provides air circulation indirectly into the residential unit. The residential unit included the largest floor area and volume, 20.0m^2 and 57.40m^3, of the four residential colleges. The residents have full control of the day light distribution and air circulation into the residential unit/room via the balcony at each residential unit/room and tinted window glass. Moreover, the casement and turn window aid the air flows even though the position of the windows and the building orientation are not in accordance with the wind flow direction, southwest. Although K4 is a newest residential college, the green area was 57.97% which is higher than K1 and K2 while with 'dutch gable roof' design, roof top garden was not appropriate to be implemented in the future.

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TABLE I. THE CHARACTERISTIC AND GREEN BUILDING STRATEGIES DEMONSTRATED AT K1, K2, K3 AND K4

Internal systems	Characteristic	RESIDENTIAL COLLEGE			
		K1	*K2*	*K3*	*K4*
Built-form configuration, orientation, site layout planning & features	Form of building	Low rise	Low-rise	Low-rise	Low-rise
	Building layout	Linear arrangement	Linear arrangement	Courtyard arrangement	Courtyard arrangement
	Orientation to sun path	N - S, NW - SE & NE - SW	N - S	N - S	N - S & W - E
	Shape of the building's floor plate	Rectangle	Rectangle	Rectangle	L-shape
	Wind direction of the locality	SW	SW	SW	SW
	Floor level (excluding GF)	3	3	3	3
	Total floor area (m^2)	11,427.67	22,288.14	18,212.51	34,305.32
Residential unit-form & configuration	Typical room dimension (l) x (w) x (h)	4.98 x 3.3 x 2.5	4.15 x 3.88 x 2.91	5.0 x 3.4 x 2.77	5.0 x 4.0 x 2.87
	Typical room's floor area (m^2)	16.43	16.10	17.00	20.00
	Typical room volume (m^3)	41.09	46.86	47.09	57.40
	Typical of corridor width (m)	1.50	1.65	1.87	1.6
Enclosural & façade design	Design	Glare protection, adjustable & fix natural ventilation option	Glare protection & adjustable natural ventilation option	Glare protection & adjustable natural ventilation option	Glare protection & adjustable natural ventilation option
	Window area (m^2)	2.60	0.82	6.46	Type A : 1.65 / Type B : 4.12
	Window to wall ratio	0.32	0.07	0.69	Type A : 0.14 / Type B : 0.36
	Operable window area (m^2)	2.60	0.82	4.07	Type A : 1.10 / Type B : 2.75
	Operable window to wall ratio	0.32	0.07	0.43	Type A : 0.1 / Type B : 0.24
	Window design	Louver window/Jalousie	Louver window/Jalousie	Centre pivot & awning	Casement & Turn window
	Location	N - S, NW - SE & NE - SW	N - S	N - S	N - S & W - E
Solar control devices	Horizontal overhangs along the wall with windows	✓	✓	✓	✗
	Vertical overhangs along the wall with windows	✓	✗	✗	✗
	Tinted window glass	✗	✗	✓	✓
	Balcony/Veranda	✗	✗	✗	✓
	Deep recesses	✗	✓	✓	✓
	Internal courtyard	✗	✗	✓	✓
Passive daylight concepts	Articulated light shelves	✓	✓	✓	✗
	Light pipes	✗	✗	✗	✗
	Internal courtyard	✗	✗	✓	✓
	Balcony/Veranda	✗	✗	✗	✓
Wind & natural ventilation	Window opening with horizontal adjustable/ closing devices	✓	✓	✓	✗
	Window opening with vertical adjustable/closing devices	✗	✗	✓	✓
	High level fixed/adjustable exhaust opening	✓	✓	✓	✗
	Low level fixed/adjustable exhaust opening	✓	✗	✗	✗
	Wing walls above residential unit entrance door & wall	✓	✗	✓	✗
	Wall opening (create wind pressure inside room)	✗	✗	✓	✗
	Balconies/Veranda	✗	✗	✗	✓
	Internal courtyard	✗	✗	✓	✓
	Location of opening with respect to wind direction	✓	✗	✗	✗
Landscaping	Green area (%)	52.25	52.65	60.70	57.97
Others	Corridor	Adjustable & fixed opening devices at the both end of corridor at each level	Fixed opening at the middle & both end of corridor at each level	Open corridor at each level which facing to internal courtyard	Open corridor at each level which facing to internal courtyard
	Staircase area	Small fixed opening devices	Small adjustable & fixed opening devices	Open staircase area	Open staircase area

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The ranking of green building strategies implementation on in these four residential colleges was found to be in the following order, K3>K4>K1>K2. This study found that out of the four colleges there are more wind and natural ventilation design strategies being implemented as compared to passive daylight strategies.

The electricity use and the total floor area (TFA) at the four residential colleges are presented in TABLE II. As described, K4 had the largest TFA, 34,305.32m^2, followed by K2 with 22,288.14m^2, and K3 with 18,212.51m^2. K1 as the oldest residential college was the smallest building / capacity among these four with 11,427.67m^2 of TFA. Statistically, K4 achieved the best result on electricity usage as it attained the lowest mean of Energy Efficiency Index (EEI), 24.235 kWh/m^2/year, compared to the other three case studies: K1 (64.377 kWh/m^2/year), K2 (42.697 kWh/m^2/year) and K3 (34.523 kWh/m^2/year). Unfortunately, the value of median is more suitable for making comparisons among these four case studies due to the extreme usage of electricity stated at K1 and K3, when the range value exceeded 98,898 kWh and 152,408 kWh, which are noticeably higher than usual. As a consequence, the mean score of electric use is far off from the normal score or normal usage of electricity and not really representative of the performance of electric use in an appropriate manner. By using the median score, K3 stated the lowest EEI, which was 23.909 kWh/m^2/year, followed by K4 (25.273 kWh/m^2/year), K2 (42.904 kWh/m^2/year) and K1 (54.006 kWh/m^2/year). Consequently, only K3 and K4 were in the range of average electricity usage value in Malaysia which is 10 to 25 kWh/m^2/year. Regarding the Building Energy Performance (BEP), K4 stated the lowest kWh per unit of floor area, 2.000 kWh/m^2, followed by K3 (2.268 kWh/m^2), K2 (3.634 kWh/m^2) and K1 (4.572 kWh/m^2), which means that K1 still remains the highest user of electricity in five years duration.

IV. CONCLUSION

There is a significant influence on the energy performance of residential colleges by means of green building strategies. The adoption of green building strategies, a combination of enclosural and facade design, solar control devices, optimisation of natural daylight, wind and natural ventilation and landscaping, as employed in K3, clearly helped to reduce the electricity consumption per annum. The combination of internal courtyard and balconies integrated in the building design assisted in reducing electricity consumption per unit of floor area as shown in K4. Open corridor at the middle of the building layout with the linear arrangement seem not really practical for optimising daylighting and natural ventilation for energy conservation in residential college buildings. This is evidential in K2 which consumed double the amount of electricity than the average residential buildings in Malaysia, 10 to 25 kWh/m^2/year. Unfortunately, by making comparison solely between K2 and K1, which more green building strategies were implemented principally on natural ventilation, the performance of electricity consumption of K2 is much better.

TABLE II. THE ELECTRICITY CONSUMPTION AND TOTAL FLOOR AREA (TFA) AT K1, K2, K3 AND K4

The performance of electricity consumption - Monthly & Annual (kWh), BEP and EEI at residential colleges

Statistical analysis	K1 TFA : 11,427.67 m^2				K2 TFA : 22,288.14 m^2				K3 TFA : 18,212.51 m^2				K4 TFA : 34,305.32 m^2			
	Monthly	*Annual*	*BEP*	*EEI*	*Monthly*	*Annual*	*BEP*	*EEI*	*Monthly*	*Annual*	*BEP*	*EEI*	*Monthly*	*Annual*	*BEP*	*EEI*
Mean	61,307	735,679	5.365	64.377	79,304	951,643	3.558	42.697	52,396	628,752	2.877	34.523	69,282	831,378	2.020	24.235
Median	52,253	617,160	4.572	54.006	80,985	956,252	3.634	42.904	41,297	435,443	2.268	23.909	68,618	867,012	2.000	25.273
Std. Dev.	25,222.16	230,417.20	2.207	20.163	18,469.68	70,007.81	0.829	3.141	28,418.22	312,076.74	1.560	17.135	16,321.82	113,325.65	0.476	3.303
Variance	6.36E+08	5.309E+10	4.871	406.550	3.41E+08	4.901E+09	0.687	9.866	8.08E+08	9.739E+10	2.435	293.618	2.66E+08	1.284E+10	0.226	10.913
Range	98,898	513,696	8.654	44.952	93,858	175,105	4.211	7.856	152,408	602,377	8.368	33.075	71,736	263,719	2.091	7.687

Note:
TFA : Total Floor Area (m^2)
BEP : Building Energy Performance (kWh/m^2)
EEI : Energy Efficiency Index (kWh/m^2/year)

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Hence, this directly showed the effectiveness of open corridor at the middle of building layout in optimising daylighting and natural ventilation, even though it was not achievable at the same level of K3 and K4 which implemented internal courtyard of building layout.

Internal courtyards and balconies should be seriously considered as part of multi storey residential building designs due to its enormous potential for lowering energy consumptions used for mechanical cooling the internal spaces. Balconies and landscaping are able to act as buffers to protect the units from harsh solar radiation. In addition, the long daylight hours, available at a consistent rate all year long in the tropical regions should be optimised as part of the green building design principles.

ACKNOWLEDGMENT

The authors would like to thank JPPHB, UMCARES and all residential colleges on the University of Malaya campus for their permission of the auditing process including full support in supplying data to be used in this study.

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